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**Title: Impact of seismic image quality on fault interpretation uncertainty**

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## **Abstract**

Uncertainty in the geological interpretation of a seismic image is affected by image quality. Using quantitative image analysis techniques we have mapped differences in image contrast and reflection continuity for two different representations of the same greyscale seismic image, one in two-way-time (TWT) and one in depth. The contrast and reflection continuity of the depth image is lower than that of the TWT image. We compare the results of 196 interpretations of a single fault contained in the seismic with the image quality. Low contrast and continuity areas correspond to a greater range of interpreted fault geometries, resulting in a broader spread of fault interpretations in the depth image. Subtle differences in interpreted fault geometries introduce changes in fault characteristics (e.g., throw, heave) that are critical for understanding crustal and lithospheric processes. Seismic image quality impacts interpretation certainty, as evidenced by the increased range in fault interpretations. Quantitative assessments of image quality could inform: 1) whether model based interpretation (e.g. fault geometry prediction at depth) is more robust than a subjective interpretation, and 2) uncertainty assessments of fault interpretations used to predict tectonic processes such as crustal extension.

## **1. Introduction**

Interpreting seismic reflection data is the principal approach for obtaining a detailed understanding of the geological structure of the subsurface. Central to these endeavours is the ability to trace faults. The resulting interpretations of fault patterns are used to infer a wide variety of tectonic properties – for example: estimations of upper crustal stretching during lithospheric extension (e.g. Kusznir and Karner 2007), kinematic connectivity and stretching directions (e.g. Baudon and Cratwright, 2008); and polyphase reactivation and inversion (e.g. Underhill and Paterson, 1998; Badley and Backshall, 1989). Fault interpretations are important components in the prediction of hydrocarbon reservoir volumes in structural traps, and in forecasting the integrity and performance for structurally complex reservoirs (e.g. Richards et al., 2015; Yielding, 2015; Wood et al., 2015; Freeman et al., 2015). However, in publications, faults are commonly shown as single, deterministic interpretations – even though there are uncertainties in these seismic interpretations that will

39 impact on the application of the interpretation. A single seismic image can comprise a range of interpretations  
40 with intrinsic probabilities (Bond et al., 2007; Hardy, 2015). Despite the importance of fault interpretations,  
41 remarkably few publications or indeed training materials explain how faults are interpreted on seismic  
42 reflection profiles, nor discuss the uncertainties in the interpretations. Here we explore how image quality  
43 impacts fault interpretation, using outputs from an interpretation exercise.

44         Faults may be characterized as quasi-planar features that offset geological markers. It is rare that the  
45 fault surfaces themselves generate seismic reflections. Therefore, on seismic images, fault geometries are  
46 established chiefly by linking the terminations of stratal reflectors. (e.g. Bahorich and Farmer, 1995). However,  
47 there are many other explanations for reflector termination, some geophysical (e.g., noise, processing effects,  
48 anomalous changes in velocity), some geological (e.g. depositional facies changes, channels, unconformities),  
49 that are not always easy to distinguish, so there are ambiguities in fault interpretation. Subtle differences in  
50 fault interpretation introduce changes in the geometric characteristics of the faults (e.g., throw, heave), with  
51 for example impact on the determination of stretching factors for sedimentary basins. In basins that are in a  
52 late stage of being explored, 3D seismic data is often employed because it generally provides a higher spatial  
53 resolution and geometric continuity compared with even closely-spaced grids of 2D seismic profiles  
54 (Cartwright and Huuse, 2005; Gao, 2009), but significant uncertainty in structural interpretation can still exist.  
55 Regardless of the development of 3D seismic methods, 2D data continues to underpin regional tectonic studies  
56 and frontier basin exploration (e.g. Platt and Philip, 1995; Thomson and Underhill, 1999; Gabrielsen et al.,  
57 2013). Much of the understanding of fault geometry is based on heritage 2D data from the 1980s (e.g. Freeman  
58 et al., 1990), even if enhanced by subsequent 3D studies (e.g. Cartwright and Huuse, 2005). Furthermore,  
59 training materials in fault interpretation (e.g., Shaw et al. 2005), as well as knowledge-sharing resources (i.e.,  
60 books and articles), are chiefly two-dimensional, presented in paper or on computer screen. In summary, 2D  
61 interpretation is a fundamental and important part of most seismic interpretations irrespective of whether  
62 the data is available as 2D lines or 3D volumes. In spite of its importance, the impression given by these training  
63 materials and by the expert community is that fault interpretation in seismic imagery is routine and carries  
64 little uncertainty.

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## **2. How do we see seismic images**

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Seismic data is viewed and interpreted manually as an image. There are a number of visual factors that affect how we perceive objects, including colour, intensity, hue or perspective (e.g. Froner et al., 2013).

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These factors determine the saliency of the different elements that form an image. Visual saliency refers

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to the distinctiveness of an element, i.e., the capacity to draw the attention of the viewer (e.g., Kadir and

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Brady, 2001; Kim et al., 2010), and is mainly dependent on its distinction from nearby elements (Cheng et

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al., 2011). Visual saliency produces biases in favour of the most prominent elements (Reynolds and

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Desimone, 2003), and hence influences interpretation. As such, increasing image contrast enhances

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differences between prominent elements in an image (Reynolds and Desimone, 2003).

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Classically, seismic imagery is presented as a grey-scale, although it is now commonly visualised in colour,

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using either linear or non-linear colour spectrums (Froner et al., 2013). Non-linear colour spectrums are

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often used to highlight maximum and minimum amplitude reflectors. When employing an 8-bit black and

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white computer render, image contrast represents the range in amplitude of seismic reflection data as

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256 pixels in different shades of grey. Similarly, reflection continuity (the saliency of a reflector) is

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represented by adjoining pixels of the same, or a similar, shade of grey. Modern 64-bit computers can

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display images in millions of grey or colour shades. However, human perception of images presented in

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grey scale is poorly understood and an active area of research (Song et al., 2010; Radonjic et al., 2011).

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Our aim is to test if even “simple” 8-bit grey scale visualisations of seismic images of different quality have

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an impact on interpretation outcome.

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## **3. Interpretation Experiment**

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We presented a seismic image to 196 interpreters in a controlled experiment, and compared their

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interpretations of a major fault in the seismic image, with the image quality. The seismic reflection image from

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the Gulf of Suez (Fig. 1) was presented either in two-way travel time (TWT, Fig. 1a) - 70 subjects, 36% of the

90 interpretations - or in depth domain (Fig. 1b) - 126 subjects, 64% of the interpretations (Figs. 1c and 1d,  
91 respectively). The participants were asked to “interpret the major fault crossing the section and the main  
92 sedimentary horizons as deep as they could”. They were also asked to provide further annotation and/or  
93 sketching to support their interpretations. In this contribution, we focus purely on the fault interpretations as  
94 drawn by the participants on the seismic image. Participants had up to 30 minutes to complete their  
95 interpretations. The interpreters’ proficiencies were highly diverse, and their experience ranged from  
96 unexperienced students to interpretation specialists with more than 30 years of experience.

97 The seismic section used in the experiment is a 31 km long and extended to 6 s TWT (Fig. 1a). The  
98 seismic image includes a lateral disruption of the reflections in the central part, generally interpreted as a  
99 fault, but with some degree of uncertainty as to the fault’s placement, geometry and extent. The TWT section  
100 was converted to depth using a simple velocity model in Move™, described by Eq. (1):

$$101 \quad Z = V_0 \frac{(e^{kt}-1)}{k} \quad (1)$$

102 where  $Z$  is the depth in metres,  $V_0$  is the initial velocity ( $1500 \text{ ms}^{-1}$ ),  $t$  is one-way travel time and  $k$  is  
103 the rate of change in velocity with increasing depth (0.5). The depth conversion located the bottom of the  
104 section at 10.5 km depth. The depth conversion was completed on a bitmap of the seismic reflection image,  
105 which linearly stretches the image. The result is a depth section with apparently lower reflectivity and contrast  
106 than the original TWT image and 18 % longer, due to this stretching. With the exception of depth conversion  
107 both the TWT and depth images share identical processing workflows. The actual depth conversion method  
108 used is not important for our experiment; it is the difference in image quality the process creates that concerns  
109 us.

#### 110 **4. Image Analysis**

111 The image analysis undertaken focused on the pixel intensity contrast and reflection continuity  
112 (referred to hereafter as “contrast” and “continuity”, respectively) of the TWT and depth sections (see  
113 Supplemental Figure S1). For the image analysis, each seismic image was subdivided into cells of 7.2 km  
114 (length) x 1 km (depth) (1135 x 450 pixels). The area encompassing the participants’ fault interpretations was

115 subdivided into smaller cells 1.6 km x 0.4 km (216 x 163 pixels), in order to provide detailed image analysis  
116 information in the area of interest. For ease of comparison of our results, the seismic images are both shown  
117 with a vertical scale in depth in all figures (except Fig. 1a) .

118 To analyse the image contrast we extracted grey scale distributions for the pixels in each cell for the  
119 two uninterpreted images. The distributions range from pixel number 0 (black) to 255 (white): the wider these  
120 distributions are (i.e. the more pixel values close to the extremes of 0 and 255), the more contrast the image  
121 has; the narrower the pixel distribution, the more similar the pixel values are and thus the lower the contrast.  
122 The first and third quartiles ( $Q_1$  and  $Q_3$ ) from these distributions were subtracted in order to calculate the  
123 interquartile range ( $I_Q$ ) of the distributions. We use the interquartile range as an analogue for visual contrast:  
124 the wider the  $I_Q$  of the cell, the higher the contrast and vice versa. Each cell in the images is coloured according  
125 to its  $I_Q$  value in order to display graphically the contrast analysis results.

126 To analyse the reflector continuity, the images were first converted into a binary, i.e., a black and  
127 white image. This was performed using ImageJ software (Schneider et al., 2012) by setting an automatic  
128 threshold level based on the histograms of the two images. This threshold divides the pixel histogram in two  
129 halves, assigning black or white colour to all the pixels. As a result, the seismic wave reflections are separated  
130 into isolated black bodies, corresponding to the positive amplitude reflections in this particular case, included  
131 in a white background. A macro for the software ImageJ (Heilbronner and Barrett, 2013) was used to measure  
132 and analyse these resultant bodies. In the analysis, the length of the major axis of each reflection is calculated,  
133 using a best-fit ellipse method, and each reflection is then coloured based on this length value using a colour  
134 scale.

135

## 136 **5. Interpretation Outcomes**

137 Interpretations of the major discontinuity of reflectors (faults) located in the middle of the seismic images  
138 and related splay faults (327 elements in total) were used in the analysis. Of these elements, 116 correspond  
139 to the interpretations of the TWT image (Fig. 1c) and 211 to the interpretations of the depth seismic image

140 (Fig. 1.d). In general, variability in fault placement position (the spread in fault interpretations) increases with  
141 depth, and this observation is more pronounced in those interpretations derived from the depth image. The  
142 difference in fault placement spread between the two images is at a maximum at 5 km depth. Below this point,  
143 the amount of interpreted faults dipping to the right is greater in the depth section (23 faults) than in the TWT  
144 section (5 faults). The effect of the difference in the populations of TWT and depth interpretations was  
145 analysed, by randomly selecting 70 of the depth interpretations for comparison with the TWT  
146 interpretation population of 70. As these were found to be similar to the full depth interpretation analysis,  
147 we conclude that population size had no effect on the results.

148 Quantification of the variability in fault placement for the interpretation populations were computed  
149 at nine depth markers in each seismic image (Fig. 2). At each depth marker the four quartiles and outliers  
150 positions for the fault interpretation populations were calculated (results of the analysis are shown in Fig. 2,  
151 overlaying the image analyses). The inter quartile fault range (the distance between quartile 1 and quartile 3)  
152 provides a good estimation of the fault placement spread within each of the interpretation populations at a  
153 given depth (continuous black lines in Fig. 2, created from joining the quartiles between depth markers). We  
154 use the inter quartile range of fault placement within each fault interpretation population as an indicator of  
155 fault placement uncertainty for each seismic image. The inter quartiles show that fault spread remains similar  
156 in the upper 3.5 km. From 3.5 km downwards, the inter quartile fault range in the depth image increases until,  
157 at the base of the seismic image, the inter quartile width is twice that observed in the TWT image. The increase  
158 in fault spread defined by the inter quartile trend linearly increases in the TWT image with depth. In the depth  
159 image the 1<sup>st</sup> interquartile follows a similar path to that of the TWT image, but the 3<sup>rd</sup> interquartile is more  
160 heterogeneous (wavy) and is offset to the right with respect to the 3<sup>rd</sup> interquartile line in the TWT image.  
161 Meanwhile, the outliers (dashed black lines in Fig. 2) show a similar general pattern with fault spread  
162 increasing with depth, but with a greater variability and heterogeneity. The fault placement outliers for the  
163 fault interpretations of the TWT image show a convergent trend down to 2 km in width at circa 4 km depth,  
164 before the fault placement spread increases to almost 15 km at the base of the image. The fault placement  
165 outliers from the depth interpretation show a relatively constant spread (circa 4.5 km width) down to 3 km



depth. Below this point, fault spread increases with depth resulting in a 15 km spread in fault interpretations at the base of the seismic image. There is also a clear difference in the length of the faults interpreted. The depth of the first and last point of the faults were measured, resulting in an average depth of 4.7 km and 6.6 km for the faults interpreted in TWT and depth, respectively.

## 6. Image Quality

### *Image contrast*

Contrast in the TWT seismic image is almost three times greater than in the depth image (Fig. 1c and 1d). Detailed contrast analysis of both seismic images show a decrease in contrast with depth as well as higher contrast to the left of the fault location as compared to the right (Fig. 2a and 2b). There is a visible spatial association between lower contrast areas in the seismic imagery and a larger spread in fault placement certainty (Fig. 2a and 2b). This effect is especially visible in areas with very low  $I_Q$ , which correspond to maximum fault placement dispersion (i.e., dark green and blue colours in Fig. 2b). In the TWT seismic image, the  $I_Q$  values remain moderate when compared to the depth image. This may account for the smaller inter quartile range in fault placement in the lower half of the TWT image in comparison to the depth image (Fig. 2b).

The outlier fault interpretations (dashed lines in figure 2a and 2b) are also likely to have been affected by image contrast; indications of this influence can be seen in figure 2a where the left outlier line follows the yellow/green pixel contrast binning boundary at 2.5 to 7 km depth. The convexity of the right outlier towards the third quartile at 3.5 km depth and circa 15 km distance along the TWT seismic image was associated with the existence of higher contrast cells (yellow colours) in comparison to surrounding cells at this point (Fig. 2a).

### *Reflection continuity*

Reflection continuity decreases with depth in the seismic images and to the right of the main fault. Reflection continuity is, on average, 63% smaller in the depth image than in the TWT image (Fig. 2c and 2d). We associate this dramatic reduction in continuity to the decrease in contrast as a result of the depth conversion. Interpreted faults tend to cross areas with lower reflection continuity. This is not surprising, as

192 faults that cut and disrupt rock layers with the same reflective physical properties would create low reflection  
193 continuity. The fault interpretations coincide with where reflectors from the left join those coming from the  
194 right, at approximately 13-16 km along the seismic image, at circa 6 km depth. The  $Q_3$  of the TWT  
195 interpretations follow this boundary. In the depth seismic image this joining of reflectors is less clear  
196 (potentially due to the lack of reflectivity/continuity), and the 3<sup>rd</sup> quartile is more variable, especially in the  
197 deeper part below 5 km. The greater amount of faults dipping to the right below 5 km depth in the depth  
198 image can be explained by a lack of reflection continuity at distances along the section line greater than 13  
199 km, and 5km depth (Fig. 2d). In the TWT image, right-dipping faults have to be interpreted crossing strong,  
200 continuous reflections below 5 km, and most right -dipping fault interpretations stop at a shallower depths  
201 (from 17 fault interpretations at 3 km depth to only 5 at 5 km depth). In the depth image, the reflections are  
202 more discontinuous and fault interpretations continue to greater depths. The extent of the outliers also seems  
203 to be affected by reflection continuity. In the TWT seismic image for example, the right outlier line, coincides  
204 with a break in reflection continuity between 4 -10 km depth (Fig. 2c); in the depth image, the right outlier  
205 stays to the left of a package with more continuous horizontal reflections, located at 2.5 to 5.5 km depth (Fig.  
206 2d).

### 207 *Combined image analysis*

208 The analysis of contrast and continuity highlighted spatial associations between image quality and  
209 fault interpretation (Fig. 2a to 2d). In reality the image, as viewed by the interpreter, is the result of combining  
210 both contrast and continuity. In an attempt to merge the results of the contrast and continuity analyses, the  
211 continuity analysis was converted into a cell model, based on the contrast grid. This conversion assigned the  
212 maximum continuity value contained within a cell, to each cell in the grid. To merge the analyses, cells in the  
213 new continuity cell model were multiplied with the values from the respective cells from the contrast analysis.  
214 In spite of the potential different impact of the two parameters on the interpreters and their relative co-  
215 dependency (i.e., enhancing the contrast can enhance the continuity), creating a combined parameter  
216 provides a general visualisation of image quality. The results were normalized by representing the maximum

217 value as 100 and the minimum as zero. The resulting merged models for the depth converted TWT and depth  
218 images are shown in Figures 2e and f.

219         There is a diffuse horizontal boundary in the merged values in the TWT image at circa 4.5 km depth  
220 (Fig. 2e), marking a change from 'green' and hotter colours at shallower levels to lower 'blue' values as depth  
221 increases. This 4.5 km depth marks the point at which the distance between the 1<sup>st</sup> and 3<sup>rd</sup> quartiles increases  
222 from 523 m to more than double (1234 m) at the bottom of the section. This boundary also coincides with the  
223 average depth of the interpreted TWT faults, suggesting that it marks a clear increment in the uncertainty of  
224 the image for interpretation. Faults are interpreted until a deeper point in the depth image, potentially  
225 because this boundary in image quality is less perceptible. The positions of the outlier interpretations show a  
226 greater change, from a narrow converging spread to divergent with the spread increasing with depth. In the  
227 case of the depth image (Fig. 2f) this boundary is less noticeable, possibly due to the overall low values, poor  
228 image quality, although fault spread does increase with depth below 4.5 km. The results suggest that there  
229 may be a contrast and continuity threshold within the seismic images beyond which the fault interpretations  
230 are almost unconstrained by the data.

231

## 232 **7. Impact on Interpretation**

233         The experiment outlined above shows that image contrast and the continuity of features both impact  
234 on the interpretation outcome of the seismic imagery. Interpreters are less prone to cross stratal reflections  
235 if they are "strong" (i.e., high contrast and high continuity) and where reflections are "weak", uncertainty in  
236 interpretation increases. In general, enhancing image contrast helps to constrain the interpretation, as seen  
237 in the TWT image where image contrast is three times that of the depth image and the fault placement  
238 population shows a narrower spread and shorter faults. A similar pattern is observed for reflection continuity,  
239 where high reflection continuity also results in a narrower fault placement spread and shorter fault  
240 interpretations. The differences in fault spread observed determine predicted fault heave; resulting, for  
241 example in regional sections, in significant differences in crustal stretching predictions. Further work to assess

242 the relative contributions of contrast and continuity to visual image quality to create a single weighted  
243 parameter would provide a fully quantified visualisation of image quality.

244 The two images were presented in different domains (TWT and depth), resulting in an 18% longer  
245 vertical scale in the depth image which could have changed the perception of the fault geometries to  
246 interpreters. However, our correlations suggest that image quality had the major influence on interpretation  
247 choice. We note that the average depth of the faults interpreted in the TWT image coincides with a boundary  
248 in depreciating image quality in the combined analysis. Although our results show that depth conversion  
249 choices (including the method used) change seismic image quality, all image manipulations have the potential  
250 to change interpretation outcomes. We therefore need to better understand image perception so that such  
251 image manipulations do not arbitrarily influence or bias interpretation outcome.

252 For a fixed binary threshold, image contrast and continuity are associated parameters, so increasing  
253 image contrast can artificially increase continuity. This correlation causes issues in determining the best  
254 methods for enhancing imagery in order to maximise interpretation effectiveness. It also has impacts on the  
255 processing of seismic data and the model chosen to create an image. Initial processing models generally  
256 assume a sub-horizontal, sub-parallel reflector stratigraphy with minimal disruption. Thus, they enhance  
257 reflector continuity. Our results, albeit based on TWT and depth imagery rather than different processing  
258 models, show that reflector continuity is spatially related to fault placement certainty. The processing of strong  
259 reflector continuity in seismic image data may result in greater constraint, or certainty, in fault placement than  
260 is warranted by the original data. Processing models must therefore be chosen carefully and interaction  
261 between the processor and the interpreter encouraged.

262 The results of the image analysis imply that there is a threshold at which seismic image data is too  
263 indeterminate (i.e., not enough contrast or continuity) to drive the interpretation. Quantitative image analysis  
264 could be used to determine the extent of an interpretation that is data-supported and areas that are more  
265 subjective. To create interpretations for under-constrained problems, reference models can be employed such  
266 as of fold or fault shape. These reference models can be based on mechanical and geometric rules: e.g. angle

267 of faulting, based on Andersonian mechanics (Anderson, 1905, 1951); or depth to detachment for faults  
268 (Chamberlin, 1910), based on mass balance principles (Dahlstrom, 1969; Elliot, 1983). Indeed, Bond et al.  
269 (2012) show that in areas of poor constraint, simple geological reasoning and reconstruction analysis can be  
270 used to reduce interpretation uncertainty. The method proposed in this work opens the door for a workflow  
271 for image quality assessment to indicate those occasions when model-based interpretation (e.g. fault  
272 geometry prediction at depth) maybe more robust than the subjective fault interpretation of a geologist. Of  
273 course, these two approaches are complimentary: image analysis may aid the interpreter in determining when  
274 geometric modelling may be useful, and when interpretation uncertainty and therefore potential risk is high.

275 Even in the advent of more complex visualisation through computing and screen technology, including  
276 the use of colour and a greater pixel spectrum, interpretation uncertainty is determined by the quality of a  
277 seismic image. Understanding the impact of image quality on seismic interpretation, using an 8 bit grey scale  
278 image, provides a basis from which to investigate more complex aspects of visual perception including colour  
279 and luminescence. This work requires interdisciplinary research with cognitive scientists, neurologists and  
280 others to fully understand how best to represent seismic imagery to maximise interpretation efforts.

281 A key finding of our experiments is that there are significant variations in the interpretation of fault  
282 geometries as depth increases in the section. This reflects the decay in image quality with depth. This  
283 uncertainty may be important – for example in picking the hanging-wall cut-offs of stratal reflectors on normal  
284 faults to correlate with those in the footwall that are otherwise well-imaged. This, in turn, influences  
285 determinations of fault heave – information that is critical for constructing maps that show fault linkages in  
286 sedimentary basins and for determining net extension of the upper crust. These inherent uncertainties arising  
287 from image quality are generally unreported in larger-scale studies of fault patterns. Therefore, the maps and  
288 net extension calculations used in many tectonic studies carry unknown errors.

289

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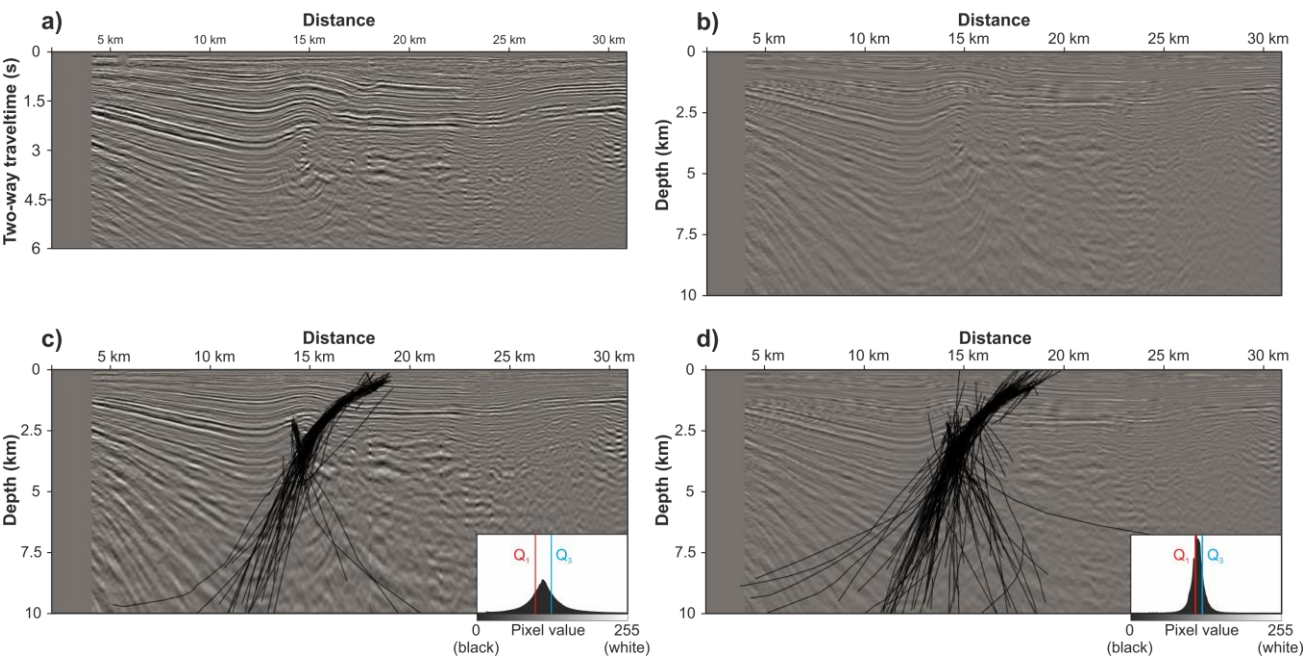
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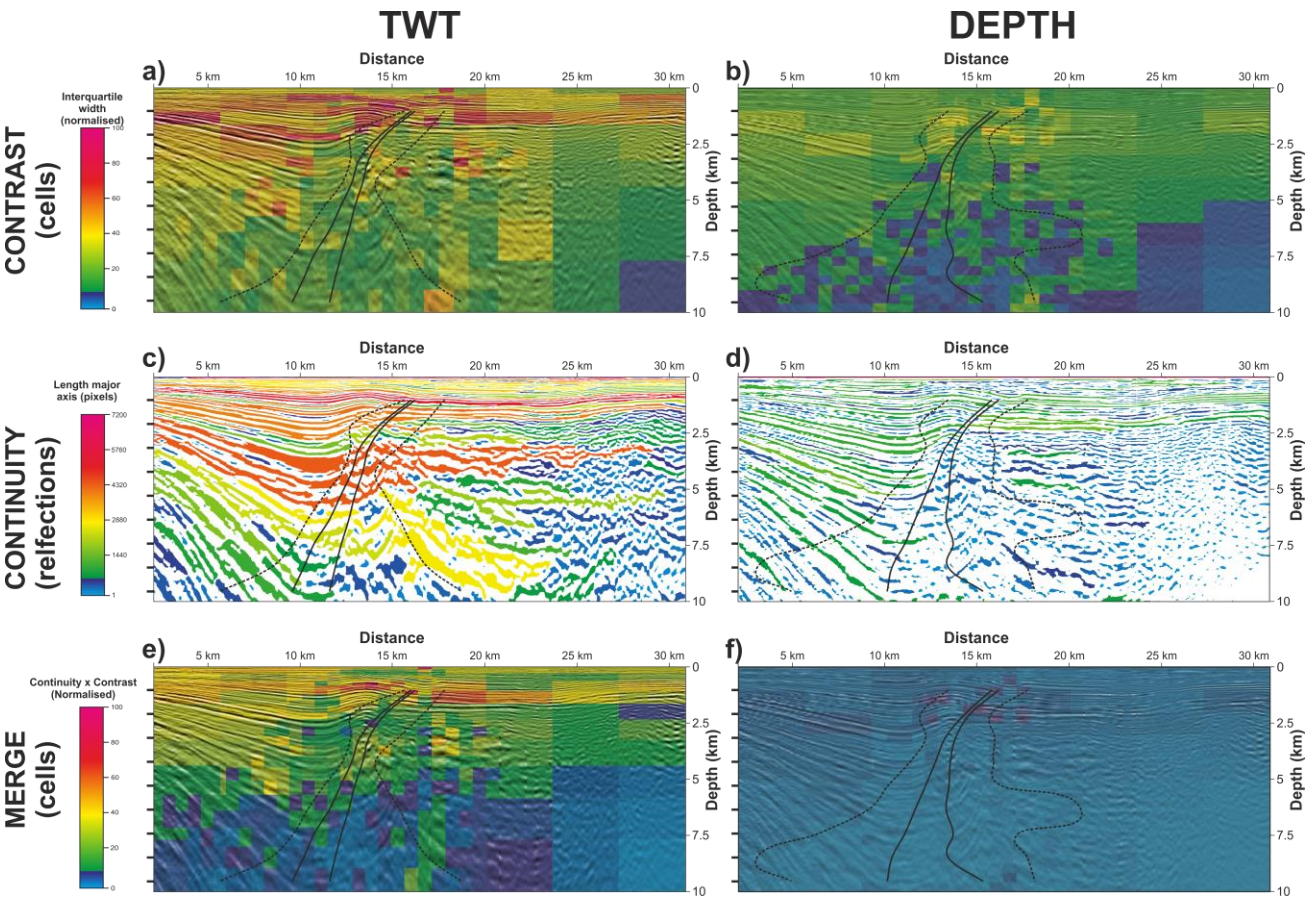


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369 **Figure 1**

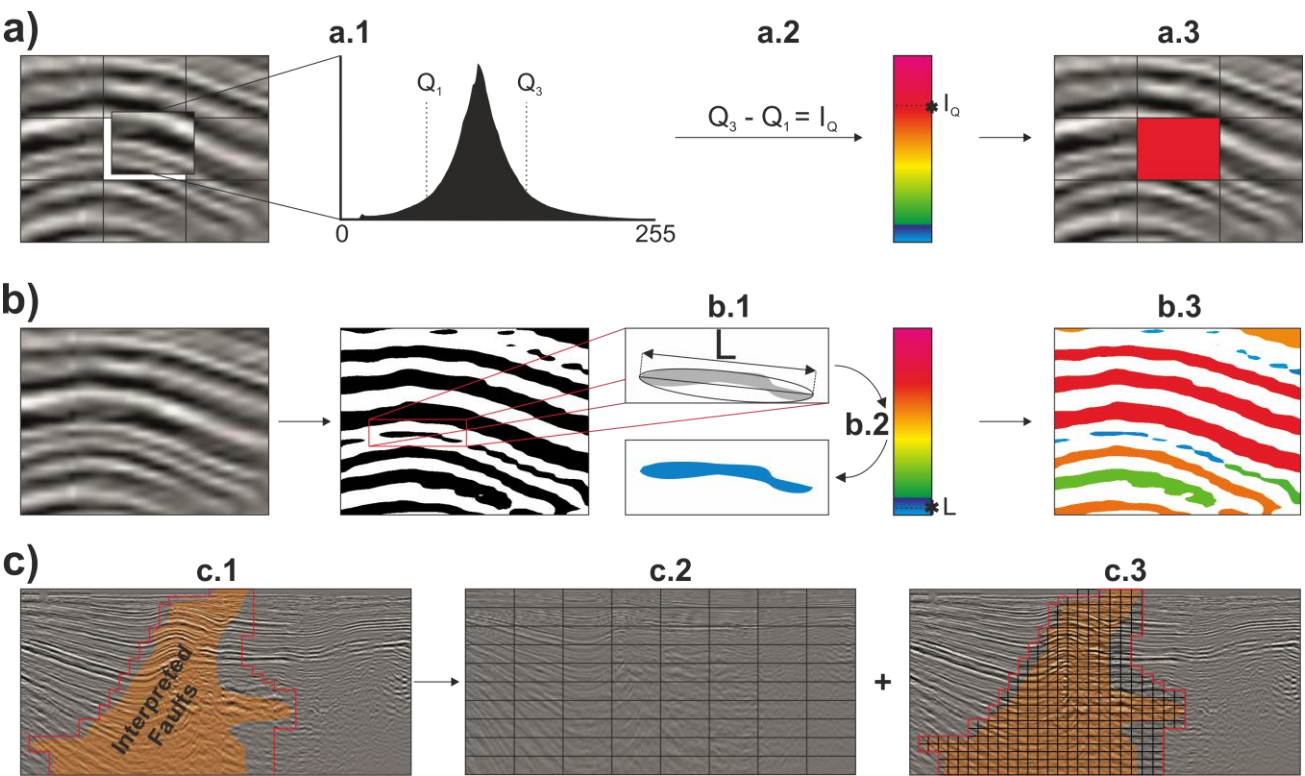


372 **Figure 2**



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## Figure captions

**Figure 1:** seismic sections used in the interpretation experiment. **(a)** Seismic section in two-way travel time (TWT). **(b)** Seismic section in depth. **(c)** and **(d)** Stacked results of the interpreted faults in TWT and depth (respectively). The figure includes the histogram of the corresponding section. In the histograms, the X-axis represents the possible grey values (from 0-black to 255-white) and the Y-axis the number of pixels found for each value. Note that the sections conserve the vertical scale in which they were presented to the participants and that the results in TWT were converted to depth, to be comparable with those interpreted in the Depth section. The sections are courtesy of BP/GRUPCO.

**Figure 2:** Results of the analysis carried out in the TWT **(a, c and e)** and Depth **(b, d and f)** seismic sections with the respective fault spread superimposed (outlier limits marked with dashed lines, 1<sup>st</sup> and 3<sup>rd</sup> quartile marked in continuous lines). **(a)** and **(b)** contrast analysis – warm colours represent high values in interquartile difference (i.e., high contrast) and cold colours represent low values (i.e., low contrast); **(c)** and **(d)** continuity analysis – reflections coloured according to the length of their major axis, with warm colours indicating long lengths (i.e., high continuity) and cold colours short length (i.e., low continuity); **(e)** and **(f)** merge of the two analysis – the results have been combined in a 1:1 relation, that is, the contrast and continuity values have been multiplied and normalised to 100. Note that the TWT results have been depth-converted for comparison (i.e., located at the same point) to the depth results. The black lines at the left side of the images mark the depths of the nine positions at which the fault placement for the interpretation populations were computed in each seismic image.

397           **Supplementary material: Figure caption**

398           **Figure S1:** Scheme of the methodology followed for the contrast **(a)** and continuity **(b)** analyses, and  
399 the areas selected for large and small cells used in the calculations (c). **(a)** The first ( $Q_1$ ) and third ( $Q_3$ ) quartiles  
400 are calculated from the pixel distributions of each subsection (a.1); the interquartile difference ( $I_Q$ , a.2) is  
401 calculated by subtracting  $Q_1$  from  $Q_3$  and the corresponding cell is coloured according to this value (a.3). **(b)**  
402 The reflections are separated and the major axis length (L) of each reflector body is calculated following a best-  
403 fit ellipse method (b.1); the reflection is coloured according to its own L value (b.2) normalized to the rest of  
404 the section (b.3). **(c)** A priority area, marked by the extent of the interpreted faults was identified (red line in  
405 c.1); all the calculations were carried out first dividing the section in large cells of 7.2 km (length) x 1 km (deep)  
406 (c.2), and then using a smaller cell size of 1.6 km x 0.4 km in the priority area (c.3).